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PATON, M.D., F.R.C.P. (*Ed.*), B.Sc.; R. STOCKMAN, M.D.,
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ON THE INFLUENCE OF MUSCULAR EXERCISE, SWEATING, AND MASSAGE, ON THE METABO- LISM.¹ By J. C. DUNLOP, M.D., F.R.C.P. (Ed.); D. NÖEL PATON, M.D., F.R.C.P. (Ed.), B.Sc.; R. STOCKMAN, M.D., F.R.C.P. (Ed.), AND IVISON MACCADAM, F.R.S. (Ed.).

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SINCE Liebig in 1842 developed his famous theory of the source of muscular energy, the influence of muscular work on the metabolism has arrested the attention of many physiologists, and much has been recorded on the subject. From previous observations, we now know that while the principal source of energy is in the non-nitrogenous constituents of the body, the nitrogenous constituents are always decomposed to a greater or less extent if the work is at all excessive. The object of the present research is to attempt to elucidate the source of the proteid material decomposed after muscular work, and generally reinvestigate the subject. The excretion of uric acid and allied nitrogenous bodies and of phosphoric acid received special attention, for an indication of the source of the proteid decomposed may be found in the influence of muscular work on these excretions.

Muscular tissue is rich in the native proteid, e.g. globulin, but is poor in nucleo proteids, and consequently, were it found that the increased excretion of nitrogen were accompanied by increased excretion of uric acid and allied bodies, along with an increased excretion of phosphoric acid, substances derived from the decomposition of the nuclein element of nucleo proteids, it would indicate that not muscle but some other tissue supplied the proteid. It is an established fact that in hunger the proteid of one tissue can be called on to supply the wants of another², and it is of interest to know whether such an

¹ The expenses of this Research were paid out of grant from the British Medical Association.

² Cp. Neumeister's *Physiologischen Chemie*. I. p. 277; and also a paper by Paton, Dunlop and others on the metabolism of Salmon in fresh water to be published shortly in the Scottish Fishery Board Reports.

abstraction of proteid from other tissues may result from excessive muscular work.

In undertaking this investigation, it appeared desirable to render the observations as complete as possible, and hence, not only were the various nitrogenous excretions in the urine dealt with, but the excretions of the principal inorganic constituents were also investigated.

The analyses were divided between the four observers. Mr Maccadam estimated the potassium and sodium in the urine, Dr Stockman estimated the uric acid and creatinin in the urine, Dr Paton the chlorides and phosphates of the urine, Dr Paton and Mr Maccadam the sulphates, and Dr Dunlop the total nitrogen, urea, extractive nitrogen and preformed ammonia of the urine and the nitrogen of the faeces and food stuffs. The general management of the observations was undertaken by Dr Dunlop.

There are two factors which must necessarily complicate observations on the effects of muscular exercise, the one sweating, the other the mechanical influence of contracting muscle on the flow of blood and lymph. These two factors we have investigated by separate experiments, adopting the dry heat of a Turkish bath to produce sweating, and general massage to imitate the mechanical influence on the blood and lymph flow.

We shall here give, firstly, a detailed statement of the experiments undertaken; secondly, a consideration of the effects produced on each of the excretions examined; and, lastly, conclusions to be derived from the results.

Reference to previous work will principally be found in the second part.

I. REPORT OF EXPERIMENTS.

Five experiments were made, of these three were to investigate the effect of excessive muscular exercise, one that of sweating and one that of massage. In all of them the general arrangement was similar. The subject was put on a rigidly fixed diet for a period of seven days. It was found impracticable to continue the conditions for a longer period. The muscular work was done on the fourth day. This gave a sufficiently long fore-period to show changes on the experiment day, and a sufficiently long after-period to show later changes.

The diet adopted was as follows:

Breakfast—Porridge and milk, biscuit and butter, and tea.

Lunch—Meat (tinned turkey, ham and tongue, minced and thoroughly mixed), biscuit and butter.

Afternoon tea—Tea, biscuit and butter.

Dinner—Meat as at lunch, rice and milk, biscuit and butter.

In addition to the above, a measured quantity of whiskey and water was daily allowed.

All the constituents of this diet were carefully measured, and of them only two, oatmeal and rice, required cooking before use: thus manipulative error was reduced to a minimum.

The supply of salt was carefully regulated, a measured quantity of a solution of salt being used daily in each experiment.

The quantities of the various ingredients are stated along with each experiment.

The methods of analysis adopted were as follows:

<i>Urine.</i>	Total Nitrogen,	Kjeldahl's method.
	Urea,	Bohland's method ¹ .
	Preformed Ammonia,	Schlössing's method.
	Extractive nitrogen,	Calculated by difference between sum of urea and ammonia nitrogen and total nitrogen.
	Creatinin,	Neubauer ² .
	Sulphates,	Neubauer ³ .
	Chlorides,	Neubauer and E. Salkowski ⁴ .
	Phosphates,	Neubauer and E. Salkowski ⁵ .
	Potassium & Sodium,	Bunsen's method.

Faeces. These were dried on a sandbath with dilute sulphuric acid, and their nitrogen estimated by Kjeldahl's method.

Food stuffs. The amount of nitrogen contained was determined by Kjeldahl's method.

Experiment A. The subject of this experiment was a naturally muscular man, æt. 28, a masseur, who for some time previously had very little exercise, and whose muscle was soft. On the fourth day he took what was for him violent exercise, which consisted of bicycling 86 miles on hilly roads. The day was wet, cold and windy. He

¹ *Archiv für d. ges. Physiol.* xxxv. p. 199. 1885.

² Salkowski and Leube, p. 111. ³ p. 175.

⁴ p. 171.

⁵ p. 183.

TABLE I. Showing amount of excretions &c. in experiment A expressed as grms. per diem except where noted.

DATE	Quantity c.c.	S. G.	Total nitrogen	URINE						Food									
				Urea	Pre- formed ammonia	Creati- ninin	SO ₃		Cl	P ₂ O ₅	K	Na							
							Total	Conju- gated											
1	1500	1020	13·56	·96	25·9	·84	·25	2·08	·89	·19	2·64	24	1·47	62·0	61·5	2000	26·3		
2	1280	1024	15·91	1·42	30·0	·84	·26	2·75	2·48	·27	18·2	2·79	2·04	5·05	25	2·24	61·5	61·5	
3	1240	1026	21·31	·96	41·8	·43	·43	2·65	2·37	·28	15·6	2·91	2·36	4·15	21	1·17	61·5	61·5	
*4	1160	1026	21·42	·97	42·6	1·02	·27	3·24	2·97	·27	17·3	2·73	2·99	3·89	9	·93	60·8	60·0	
5	950	1028	25·99	2·05	49·4	1·45	·45	·28	3·13	2·85	·28	11·8	3·66	3·68	3·59	20	1·69	59·3	60·6
6	950	1028	22·95	1·29	45·1	1·09	·57	·22	2·37	2·07	·30	12·1	3·06	2·07	3·21	33	2·97	60·6	61·1
7	1050	1030	22·05	·63	44·6	1·08	·54	·20	2·76	2·47	·29	18·2	2·41	3·65	4·75	52	2·47	61·1	61·5

* On this day the exercise was taken.

complained of great fatigue, said that he felt hot in bed and could not sleep for several hours after retiring on the night after exercise. He suffered from stiffness in legs and arms and great thirst for two days after the exercise. Details of his diet, excretions, etc., will be found in the following tables. It will be seen in these tables that his supply of nitrogen was unnecessarily large, so large that his metabolism was hardly in a state of equilibrium before the third day; allowance must be made for this in considering the figures. His supply of water, fixed for himself on the first day, was too small, but he adhered strictly to it to the end of the experiment.

TABLE 2. Showing constituents of diet used in Exp. A and amount of nitrogen contained. Quantities expressed as grms. except where noted.

Food stuff	Quantity per diem	Nitrogen per cent.	Nitrogen per diem
Meat	350	2·50	8·9
Biscuit	260	2·55	6·6
Milk	1000 c.c.	.59	5·9
Oatmeal	120	2·60	3·1
Rice	120	1·31	1·6
Butter	60	.26	.2
Sugar	45	0	
Whiskey	100 c.c.	0	
Salt solution	20 c.c.	0	
Tea tabloids, 6		trace	
Total nitrogen of diet			26·3

This diet has an energy value of 32628¹ calories, equivalent to 535 per kilogramme of body weight.

Experiment B. The subject of this experiment was a physician of 35 years of age. He was in worse training than the subject of exp. A., his muscles being very soft. His exercise consisted of walking 13 miles, riding 12 miles, digging 1 hr. and 40 min., and ascending a hill of the height of 800 feet. After exercise he complained of being very tired, disinclined for food at dinner-time, tendency to sleep then, but want of sleep in bed. On the following day his appetite was poor, his tongue coated with white fur, he felt tired and in the afternoon became very stiff. On the second day after exercise he was stiff in the forenoon but that wore off towards evening. On the third day

¹ The composition of the food was calculated from diet tables, except the proteids, which were estimated from the nitrogen as shown in the tables. The fat of the "meat" was estimated by extraction with ether in Soxhlet's apparatus.

TABLE 3. Showing amount of excretions &c. in experiment B expressed as grms. per diem except where noted.

DATE	Qnan- tity c.c.	S. G.	Total nitrogen	URINE						WEIGHT			Food				
				Extrin- cative nitrogen	Urea	Pre- formed ammonia	Uric acid	SO ₃		Cl	P ₂ O ₅	K	Na	Morning	Evening	Nitrogen	Water c.c.
								Total	Ordinary								
1.																	
2	1860	1015	14.13	.56	27.7	.68	.47	2.19	1.96	.16	7.47	2.52	1.76	3.35	18.8	1010	
3	1710	1015	12.65	.68	24.4	.62	.48	2.02	1.88	.14	8.76	2.87	2.03	3.69	,,	1010	
*4	830	1026	13.80	.73	26.9	.81	.42	2.67	2.51	.15	5.68	2.38	1.48	2.27	,,	1510	
5	870	1024	16.79	1.05	31.8	1.07	.51	2.36	2.23	.13	4.33	3.60	1.25	1.70	,,	1010	
6	1440	1016	14.09	.68	27.5	.73	.48	1.97	1.83	.14	9.25	3.31	1.71	3.54	,,	1010	
7	2390	1010	11.92	.74	22.9	.59	.64	1.84	1.69	.15	9.14	2.61	1.69	3.85	,,	1010	

* On this day exercise was taken.

he was completely recovered. The exercise was taken on a hot day, and was accompanied by free perspiration, especially profuse when digging. An extra supply (500 c.c.) of water was taken on the exercise day. His diet was supplemented by a small portion of cheese at dinner.

The method of estimating creatinin was found to be so laborious and unsatisfactory that it was omitted in this and the subsequent experiments. It was considered unnecessary to analyse the faeces.

TABLE 4. Showing constituents of diet used in Exp. B. Quantities expressed as grms. except where noted.

Food stuff	Quantity per diem	Nitrogen per cent.	Nitrogen per diem
Meat	187	2.5	4.7
Biscuit	203	2.14	4.3
Milk	1000 c.c.	.59	5.9
Oatmeal	80	2.6	2.1
Rice	30	1.31	.4
Butter	34	.26	.1
Cheese	30	4.51	1.3
Sugar	45	0	
Whiskey	120 c.c.	0	
Salt solution	20 c.c.	0	
Tea tabloids, 8		trace	
Total nitrogen of diet			18.8

This diet has an energy value of 21350 calories, equivalent to 337 per kilogramme of body weight.

Experiment C. The subject was a physician, 31 years of age, who at the time was in good muscular training, having exercised regularly on a bicycle for some time previously. His exercise consisted of bicycling 50 miles, walking 5 miles and digging for 2 hours. When digging he made and refilled a trench 12 ft. by 4 ft. by 3 ft. 6, and in doing this lifted over five tons of soil. After exercise he was very tired and complained of great thirst, but slept soundly. There was no rise of temperature. On the following days the only effects noted were thirst and a slight feeling of fatigue. There was practically no after stiffness. Extra water was taken as is noted in table 5 on the fourth, fifth and sixth days. The exercise in this experiment was also done on a hot day and produced very free perspiration. In his diet biscuit was substituted by rusk.

TABLE 5. Showing amount of excretions &c. in experiment C expressed as grms. per diem except where noted.

DATE	Quan-tity c.c.	S. G.	Total nitrogen	URINE						WEIGHT			Food	
				Pre-formed ammonia	Urea	SO ₃			Na	Morning kgm.	Evening kgm.	Nitrogen	Water c.c.	
						Total	Ordinary	Conju-gated						
1										67.1	67.7	17.8	1550	
2	1770	1016	15.04	.88	28.6	.99	.46	2.38	.09	6.44	3.38	67.1	67.7	
3	1690	1016	12.67	.90	24.1	.63	.45	2.21	.09	6.54	3.14	2.95	67.5	
*4	1020	1026	14.46	.71	28.0	.82	.34	3.47	.07	6.29	3.16	3.27	3.44	
5	700	1027	16.03	.58	33.1	.91	.42	2.37	.05	4.39	2.78	1.12	1.01	
6	1310	1020	18.54	.90	35.8	1.18	.30	2.35	.13	7.47	2.93	1.06	1.02	
7	2050	1012	15.49	.84	29.7	1.01	.43	2.24	.12	8.21	2.64	1.40	3.63	
												66.6	64.8	
												,,	2050	
												,,	2050	
												,,	1550	
												,,	1550	

* On this day exercise was taken.

TABLE 6. Showing constituents of diet used in Exp. C. Quantities expressed as grms. except where noted.

Food stuff	Quantity per diem	Nitrogen per cent.	Nitrogen per diem
Meat	200	2·5	5·0
Rusk	212	1·83	3·8
Milk	1000 c.c.	.59	5·9
Oatmeal	80	2·6	2·1
Rice	60	1·31	.8
Butter	90	.26	.2
Sugar	45	0	
Whiskey	150 c.c.	0	
Tea tabloids, 8		trace	
Salt solution	20 c.c.	0	
		Total nitrogen of diet	17·8

This diet has an energy value of 26210 calories, equivalent to 400 per kilogramme of body weight.

Experiment X. The subject was the same as in experiment C. On the fourth day sweating was produced by two Turkish baths, the duration of each being forty minutes. His weight was not noted immediately before and after the first bath, but was so before and after the second, and showed a loss of weight amounting to 700 grms. ($1\frac{1}{2}$ lb.) to have taken place during the forty minutes. The only after effects noted were slight lassitude after the baths and thirst during the following two days. No extra water was taken on the day of the baths or afterwards. There was no massage after the baths. The diet was supplemented by a little cheese, and some of the tea was replaced by coffee. A large quantity of infusion of coffee was made on the first day and the daily allowance measured from that. Estimations of uric acid and fixed alkalis were not made in this and subsequent experiment.

Experiment Z. The subject was a very thin man, a worker in the Royal College of Physicians' Laboratory, age 37. On the fourth day he was twice subjected to one hour's strong general massage by Dr H. A. Laing, two hours in all. There were no obvious after effects and none of the stiffness, which usually results from such massage. There was some error in the collection of the urine on the seventh day, so that day's analyses are excluded from the tables. Diet was similar to that of experiment X, but smaller in amount and with the addition of a little "Bovril" (a meat extract) solution.

TABLE 7. Showing excretions &c. in experiment X expressed as grms. per diem except where noted.

DATE	URINE						WEIGHT			Food			
	Quantity c.e.	S. G.	Total nitrogen	Extractive nitrogen	Urea	Preformed ammonia	SO ₃ total	Cl	P ₂ O ₅	Morning kgm.	Evening kgm.	Nitrogen	Water c.e.
1													
2	1230	1023	14.02	.92	26.7	.79	2.34	5.22	2.70	66.4	67.1	19.6	1605
3	1300	1020	14.76	.98	28.3	.70	2.89	6.86	2.99	66.4	66.8	,,	,
*4	960	1028	13.22	1.08	24.7	.78	2.47	4.95	2.59	56.8	66.6	66.6	,
5	930	1028	14.69	1.02	27.9	.80	2.37	5.08	2.58	66.0	67.1	67.1	,
6	1050	1028	16.34	1.27	30.8	.84	2.42	2.90	2.90	66.4	67.5	67.5	,
7	1695	1018	15.55	1.05	29.2	1.04	2.49	5.15	2.41	66.7	67.5	67.5	,

* On this day profuse perspiration was induced.

TABLE 8. Showing constituents of diet used in Exp. X. Quantities expressed as grms. except where noted.

Food stuff	Quantity per diem	Nitrogen per cent.	Nitrogen per diem
Meat	200	2·5	5
Oatmeal	40	2·6	1
Biscuit	336	1·85	6·2
Rice	30	1·31	.4
Milk	1000 c.c.	.59	5·9
Butter	90	.26	.2
Cheese	18	4·25	.7
Coffee (infusion)	350 c.c.	.05	.2
Tea tabloids, 4		trace	
Sugar	45	0	
Whiskey	150 c.c.	0	
Salt solution	20 c.c.	0	
		Total nitrogen of diet	19·6

This diet has an energy value of 28700 calories, equivalent to 415 per kilogramme of body weight.

TABLE 10. Showing constituents of diet used in Exp. Z. Quantities expressed as grms. per diem except where noted.

Food stuff	Quantity per diem	Nitrogen per cent.	Nitrogen per diem
Meat	150	2·5	3·7
Oatmeal	40	2·6	1
Biscuit	168	1·85	3·1
Milk	250 c.c.	.50	1·2
Rice	30	1·31	.4
Butter	60	.26	.1
Cheese	10	4·25	.4
Coffee (infusion)	350 c.c.	.05	.2
Bovril (solution)	200 c.c.	.28	.6
Tea tabloids, 3		trace	
Sugar	45	0	
Whiskey	120 c.c.	0	
Salt solution	30 c.c.	0	
		Total nitrogen of diet	10·7

This diet has an energy value of 19840 calories, equivalent to 355 per kilogramme of body weight.

TABLE 9. Showing excretions &c. in experiment Z expressed as grms. per diem except where noted.

DATE	URINE						WEIGHT			FOOD		
	Quantity c.c.	S. G.	Total nitrogen	Urea	Preformed ammonia	SO_3 total	C ₁	P_2O_5	Morning kgm.	Evening kgm.	Nitrogen	Water c.c.
1												
2	1300	1017	9.24	1.03	15.9	.78	1.26	9.70	1.56	56.3	10.7	1465
3	1150	1020	9.07	.68	16.5	.59	1.31	9.96	1.38	55.4	,,	,
*4	1165	1018	8.99	.81	16.4	.65	1.18	6.71	1.85	56.2	,,	,
5	1420	1017	9.37	.67	17.5	.65	1.30	1.96	1.96	56.3	,,	,
6	1542	1016	9.12	.89	16.5	.61	1.13	8.47	2.01	55.9	,,	,
7										55.6	56.2	,,

* On this day the subject was massaged.

II. A CONSIDERATION OF THE EFFECTS PRODUCED ON EACH OF
THE EXCRETIONS EXAMINED.

The quantity of urine passed. In the following table, No. 11, will be seen the result of our observations as to the influence of muscular exercise, sweating, and massage, on the amount of urine passed. When considering this table it must be remembered that 500 cc. extra water were taken in experiment B on the fourth day, that of exercise, and in experiment C on the fourth, fifth, and sixth days, and that with these exceptions the supply of water was constant throughout each experiment.

TABLE 11. Showing amount of urine passed in each experiment.
Expressed as c.c.

Day	Exercise			Sweating	Massage
	A	B	C		
1	1500				
2	1280	1860	1770	1230	1300
3	1240	1710	1690	1300	1150
4	1160	830	1020	960	1165
5	950	870	700	930	1420
6	950	1440	1310	1050	1542
7	1050	2390	2050	1695	

The effect of exercise was not similar in the three experiments A, B, and C. In B and C there was a great fall on the day of exercise, the fourth, and on the following day, a smaller deficit on the sixth day, while on the seventh day there was a marked increase in the amount of urine. In these two experiments profuse sweating was noted, and it is interesting to see that the effect produced on the amount of water passed in the urine was exactly similar to that produced by Turkish baths in experiment X, a deficit for three days followed by a reactionary increase. In B and C calculation shows that the reactionary increases on the seventh day were insufficient to balance the deficits on the three previous days.

In experiment A there was no marked deficit on the experiment day, but there was a deficit on the following days. In this experiment the exercise was taken on a cold, wet day, and doubtless absence of profuse sweating explains the difference between it and B and C.

In experiment X (sweating), the effect produced, as already pointed

out, was a deficit of water in the urine on the experiment day and the two following days, and a reactionary increase afterwards, this increase was also too small to balance the previous deficits.

In experiment Z (massage) there was an increased flow of urine on the two days after the massage. An increased diuresis after massage has previously been pointed out by Hirschberg¹ and Bendix², and has been attributed to a large amount of lymph being pumped out of the tissues and brought into the general circulation.

The total nitrogen passed in the urine. As already pointed out in the introduction this excretion has received much attention from physiologists in connection with the influence of muscular work on the metabolism, and from the recent work of Argutinski³, Zuntz⁴, Pflüger⁵, Bleibtreu⁶, Krummacher⁷, Paton⁸, North⁹ and others we know that it is increased by excessive muscular work, and that the increase is principally to be found on days subsequent to the exercise, and not so much on the exercise day, as was assumed by Fick and Wislesenus in their classic experiment. Our observations agree with this conclusion, for it will be seen in Table 12, that in each experiment on muscular work there was a marked increase in the amount of nitrogen excreted, and that increase was principally on the two days after that on which the exercise was taken.

TABLE 12. Showing total amount of nitrogen excreted in each experiment. Expressed as grms.

Day	Exercise			Sweating X	Massage Z
	A	B	C		
1	13.56				
2	15.91	14.13	15.04	14.02	9.24
3	21.31	12.65	12.67	14.76	9.07
4	21.42	13.80	14.46	13.22	8.99
5	25.99	16.79	16.03	14.69	9.37
6	22.95	14.09	18.54	16.34	9.12
7	22.05	11.92	15.49	15.55	

¹ *Bulletin gen. de Thérapeutique*, 1887, p. 241.

² *Zeitschrift f. klin. Med.* 1894, p. 308.

³ *Arch. f. d. ges. Physiol.* XLVI. p. 552 seqq.

⁴ *Du Bois Reymond's Archiv*, 1894, p. 541.

⁵ *Arch. f. d. ges. Physiol.* L. p. 98. 1891.

⁶ *Arch. f. d. ges. Physiol.* XLVI. p. 601. 1890.

⁷ *Zeitschrift f. Biologie*, XXXIII. p. 108. 1896.

⁸ *Laboratory Reports of Royal College of Physicians, Edinburgh*, 1891, p. 241.

⁹ *Proc. Royal Soc.* XXXVI. p. 11. 1883.

By comparing this table with Table 11, on the diuresis, it will be seen that the excretions of nitrogen and of water do not vary proportionally, for not only is there no deficit of nitrogen on the exercise day as there is of water, but also there is no increase of nitrogen on the day when there is the reactionary increase of water.

A factor which must influence the excretion of nitrogen in the urine is the amount of sweat, this could not be estimated, but as sweat has been shown to contain a considerable amount of nitrogen¹, it is safe to assert that the total increase of the output of nitrogen was really greater than our results show.

The exact amount of this excess of nitrogen cannot be absolutely definitely stated from these observations, both on account of no measure of nitrogen of the sweat being available, and also because the preliminary periods were somewhat short. But taking the average excretion on the third and seventh days as the normal, and comparing the excretions found on the fourth, fifth, and sixth days with that, it is found that the *probable amount* of the increase amounted to between 5·3 and 7·9 grms. in each experiment. This is shown in Table 13.

TABLE 13. Showing *probable* amount of excess of nitrogen in urine produced by muscular exercise.

Day	A		B		C	
	Total nitrogen	Difference from average of 3 and 7	Total nitrogen	Difference from average of 3 and 7	Total nitrogen	Difference from average of 3 and 7
Average of 3 and 7 }	21·68		12·22		14·08	
4	21·42	-0·26	13·80	+1·54	14·46	+·38
5	25·99	+4·31	16·79	+4·53	16·03	+1·95
6	22·95	+1·27	14·09	+1·83	18·54	+4·46
Total excess of nitrogen	5·32		7·9		6·79	

Taking the amount of nitrogen in flesh (muscle) at 3 per cent., these excesses of nitrogen represent a consumption of 180 to 260 grms. (roughly half-a-pound) of flesh to have occurred as the result of excessive exercise in each of these experiments.

Experiment X shows that the amount of nitrogen in urine was not influenced by sweating as it was in experiments A, B and C by exercise. The changes observable are, that on the day when the Turkish baths were taken, the fourth, there was a small deficit of nitrogen, while on the sixth day there was a small increase, this increase, however, was less than the

¹ Argutinski. *Archiv f. d. ges. Physiol.* xlvi. p. 594. 1890.

previous deficit so that the general result was a small deficit, amounting to less than a gramme, during the period of observation. This small deficit can readily be attributed to a loss of nitrogen in the sweat, it having been shown by Argutinski¹, that the sweat collected during a day's walking exercise contained as much as .75 gramme of nitrogen.

In the massage experiment Z, the excretion of nitrogen was so steady that it may be concluded, that, in this instance at least, massage did not influence the nitrogenous excretion, a conclusion differing from that of Bendix², which was, that general massage increased the amount of nitrogen in urine as much as from 10 to 15 per cent.

From our observation on massage it may be concluded, that the physical effects of contracting muscle on the lymph flow do not materially influence the amount of nitrogen excreted in the urine, and consequently the excess of nitrogen found there after exercise indicates not an increased excretion only, but also an increased production of nitrogenous waste products.

The excretion of urea. Our observations on the amount of urea excreted in these experiments are shown in the following Table (14). They show that this excretion was increased by exercise, slightly diminished by sweating, and unaffected by massage. A comparison of this table with Table 12 shows that the total amount of nitrogen in the urine and the amount of urea vary proportionally.

TABLE 14. Showing amount of urea excreted in each experiment. Expressed as grms.

Day	Exercise			Sweating X	Massage Z
	A	B	C		
1	25.9				
2	30.0	27.7	28.6	26.7	15.9
3	41.8	24.4	24.1	28.3	16.5
4	42.6	26.9	28.0	24.7	16.4
5	49.4	31.8	33.1	27.9	17.5
6	45.1	27.5	35.8	30.8	16.5
7	44.6	22.9	29.7	29.2	

The excretion of uric acid. Table 15 shows our observations on the excretion of uric acid, in each of the experiments on the effect of muscular exercise. In it will be seen that in two experiments A and B

¹ *Archiv f. d. ges. Physiol.* XLVI. p. 594. 1890.

² *Zeitsch. f. klin. Med.* 1891, p. 308.

there was a marked increase of this excretion, while in the third experiment C there was no such increase.

TABLE 15. Showing amount of uric acid excreted in experiments A, B and C. Expressed as grms.

Day	A	B	C
1	.25		
2	.26	.47	.46
3	.43	.43	.45
4	.27	.42	.34
5	.45	.51	.42
6	.57	.48	.30
7	.54	.64	.34

The essential difference between C and the other two experiments was, that it was made on a subject who was in good muscular training, the subjects of the others not being so, and it is to this that the difference between the influence of exercise in C and the other two experiments may be attributed. The amount of sweating cannot explain the difference of the effects on the excretion of uric acid, because in both B and C there was profuse sweating, while the uric acid excretion was increased in B but not in C, and because in both A and B the uric acid excretion was increased, there being profuse sweating in one but not in the other. Other differences between C and the other two experiments will be pointed out which can also be attributed to the difference of muscular training of the subjects.

The influence of exercise on the excretion of uric acid has recently been studied by Laval¹, and he concluded that it did not increase the excretion of uric acid; his observations were made on dragoons, who were presumably in good training, and consequently his results agree with ours.

The excretion of preformed ammonia. The interest in observing the effects produced on the excretion of ammonia in urine lies principally in the fact that there is in the katabolic changes of contracting muscle a formation of acids, sarcolactic acid being formed by the oxidation of non-nitrogenous elements and sulphuric acid by oxidation of proteid matter, and these may be expected to cause an increased ammonia excretion².

¹ *Revue de Médecine*, 1896, p. 384.

² Dunlop, *This Journal*, xx. p. 82. 1896.

The results of our observation are shown in Table 16, and it can there be seen that there was an increase of this excretion in each of the experiments on the influence of muscular exercise. There was no marked effect in the experiments on sweating and massage.

TABLE 16. Showing amount of preformed ammonia excreted in these experiments. Expressed as grms. NH_3 .

Day	Exercise			Sweating X	Massage Z
	A	B	C		
1	.84				
2	.84	.68	.99	.79	.78
3	lost	.62	.63	.78	.59
4	1.02	.81	.82	.78	.65
5	1.45	1.07	.91	.80	.65
6	1.09	.73	1.18	.84	.61
7	1.08	.59	1.01	1.04	

The excretion of creatinin. The excretion of creatinin was studied in one experiment, A only, and it was found that there was a small increase on the day of exercise and on the following day, the amounts of the daily excretion being, 2nd day, .26 grm., 3rd day (lost), 4th (exercise day) .29, 5th .28, 6th .22, and 7th day .20 grms. Our result agrees with that of Oddi and Tarutti¹. It was found impracticable to continue the analyses in the other experiments.

The excretion of nitrogenous extractives. By the term nitrogenous extractives is meant, all the nitrogenous bodies in the urine which are precipitated by a reagent containing hydrochloric and phosphowolframic acids, the reagent used in Bohland's method of urea estimation; these bodies contain all the nitrogen in urine with the exception of that of urea and of ammonia. The results of our observations are shown in Table 17, and are expressed as grms. of nitrogen. The amount of extractive nitrogen varied in exactly the same way as the uric acid did, it was increased by exercise in experiments A and B where the subjects were in poor training, not increased in C where the subject was in good training, and little, if any, affected by sweating or massage.

¹ *Bol. dell' Accad. Med. di Roma*, xix. p. 2. 1893; and *Maly's Jahresberichte*, 1894, p. 542.

TABLE 17. Showing amount of nitrogen excreted as "extractives." Expressed as grms.

Day	Exercise			Sweating	Massage
	A	B	C	X	Z
1	.96				
2	1.42	.56	.88	.92	1.03
3	.96	.68	.90	.98	.68
4	.97	.73	.71	1.08	.81
5	2.05	1.05	.58	1.02	.67
6	1.29	.68	.90	1.27	.89
7	.63	.74	.84	1.05	

The excretion of sulphates. In experiments A, B and C, the amount of sulphuric acid in the urine was studied both as to its total and as to its distribution between the two forms, ordinary and conjugated or etherial, sulphates. It was found that the amount of conjugated sulphate remained constant throughout the experiments, not being influenced by muscular exercise, while the amount of ordinary sulphate showed considerable changes (*vide* Tables 1, 3, and 5). It being evident that changes of the total sulphate were due to changes of the amount of ordinary sulphates, it was considered unnecessary to do more than estimate the total sulphate in the later experiments.

The influence of exercise, sweating, and massage on the amount of sulphuric acid in the urine is shown in the following table.

TABLE 18. Showing the amount of sulphate in urine in these experiments. Expressed as grms. SO_3 .

Day	Exercise			Sweating	Massage
	A	B	C	X	Z
1	2.08				
2	2.75	2.19	2.38	2.34	1.26
3	2.65	2.02	2.21	2.89	1.31
4	3.24	2.67	3.47	2.47	1.18
5	3.13	2.36	2.37	2.37	1.30
6	2.37	1.97	2.35	2.42	1.13
7	2.76	1.84	2.24	2.49	

It will be seen in this table that in each experiment on the influence of muscular exercise, there was a distinct increase of the amount of sulphuric acid excreted in the urine after the exercise.

This excretion has been investigated in similar experiments by Munk¹, and North², and was found to be influenced by exercise in the same manner as the nitrogen excretion. Our figures corroborated theirs, for by comparing this table with Table 13, it will be seen that the two excretions, nitrogen and sulphur, were both increased in all three exercise experiments, and calculation shows that the amount of the excesses was nearly in the same proportion as that in which nitrogen and sulphur occur in proteid.

The excretion of sulphuric acid in X and Z being practically steady throughout the observation, it may be concluded that sweating and massage do not influence this excretion, this conclusion verifying our previous conclusion regarding their influence on the proteid metabolism.

The excretion of chlorides. The results of our observations are shown in the following table.

TABLE 19. Showing the amount of chloride in these experiments. Expressed as grms. Cl.

Day	Exercise			Sweating	Massage
	A	B	C	X	Z
1					
2	18.2	7.47	6.44	5.22	9.70
3	15.6	8.76	6.54	6.86	9.96
4	17.3	5.68	6.29	4.95	6.71
5	11.8	4.33	4.39	5.08	lost
6	12.1	9.25	7.47	lost	8.47
7	18.2	9.14	8.21	5.15	

In the experiment on the influence of sweating, X, it will be seen that there was an apparent diminution on the fourth day, the day when the Turkish baths were taken, and on the following day. A similar diminution is also to be seen in experiments B and C where there was profuse sweating, and in these three experiments the diminution may safely be attributed to loss of chloride of sodium in the sweat. The variations which occurred in experiments A and Z are difficult to explain.

The excretion of phosphates. The following table shows the result of our observations on the amount of phosphoric acid in the urine during these five experiments.

¹ *Du Bois Reymond's Archiv*, 1895, p. 378.

² *Proc. Royal Soc.* xxxvi. p. 11. 1883.

TABLE 20. Showing the amount of phosphoric acid excreted in the urine during these experiments. Expressed as grms. PO_5 .

Day	Exercise			Sweating X	Massage Z
	A	B	C		
1	2.64				
2	2.79	2.52	3.38	2.70	1.56
3	2.91	2.87	3.14	2.99	1.38
4	2.73	2.38	3.16	2.59	1.85
5	3.66	3.60	2.78	2.58	1.96
6	3.06	3.31	2.99	2.90	2.01
7	2.41	2.61	2.64	2.41	1.67

The influence of severe exercise is shown by these experiments not to be constant, for in A and B there was a marked increase of the excretion of phosphate, while there was no such increase in C. It has already been pointed out that the subject of C was in good muscular training, while those of A and B were not so, and that in A and B there were marked increases in the amounts of uric acid and other nitrogenous extractives (*vide* Tables 15 and 17), while in C there were no such increases. These facts point at some katabolic change taking place when a subject in poor training does excessive muscular work, and which does not take place when the subject is in good training. North examined the excretion of phosphates in his experiments¹ and concluded that it was increased by excessive exercise; our conclusion differs from his, as it requires poor training in addition to excessive exercise to produce an increase.

The massage experiment, Z, showed a small increase of the phosphate in urine, this can readily be attributed to increased excretion dependent on the increased lymph flow, bringing phosphate away from the tissues, just as the increased diuresis can be attributed to that. This being so, it is possible that the physical effect of contracting muscle on the lymph flow in those in poor training may help to produce the increased excretion of phosphate, but as the increases in the exercise experiments were much larger than that in the massage experiment, it can be concluded that this physical influence did not produce the entire increase of phosphate.

In the sweating experiment, X, there was a small diminution of phosphate in the urine, pointing to a possibility of there being a loss of phosphate in sweat.

¹ *Proc. Royal Soc. xxxvi. p. 11. 1883.*

The excretion of alkalis. The excretion of the three alkalis, ammonia, potassium, and sodium, were examined in each experiment on the influence of exercise. The excretion of ammonia has already been referred to, and shown to be increased in each case. Our observations on potassium and sodium are shown in the following table.

TABLE 21. Showing the amount of potassium and sodium excreted in these experiments. Expressed as grms. K and Na.

Day	Potassium			Sodium		
	A	B	C	A	B	C
1						
2	2.04	1.76	1.91	5.05	3.35	3.33
3	2.36	2.03	1.81	4.15	3.69	2.95
4	2.99	1.48	3.27	3.89	2.27	3.44
5	3.68	1.25	1.12	3.59	1.70	1.01
6	2.07	1.71	1.06	3.21	3.54	1.02
7	3.65	1.69	1.40	4.75	3.85	3.63

It will be seen in this table that in experiments B and C the amount of sodium in the urine was diminished after exercise, in them the excretion of hydrochloric acid was found to be diminished, and that was attributed to loss in sweat, and as it is as chloride of sodium that hydrochloric acid occurs in sweat, this explanation equally applies to the diminution of sodium in the urine.

In experiment A there was also a diminished output of sodium, but this deficit was less than it was in B and C, as might be expected from the fact that there was much less sweating in A than in B and C. Unfortunately the results of our observations on the excretion of chlorides in A are too uncertain for comparison.

The excretion of potassium is increased in two experiments, A and C, but is not increased in B, the explanation of this is not obvious.

Munk¹ studied the excretion of the inorganic constituents of urine in experiments on the influence of muscular exercise; he concluded that the excretions of phosphorus, sulphur, and potassium were all affected in a manner similar to nitrogen, all being increased when the nitrogen was increased. Our observations agree with his in so far that we found the sulphur and nitrogen excreted to be proportionally influenced, but differ from his in that we found the potassium not to be influenced in all these experiments in the same manner as the nitrogen and sulphur, and the phosphate we found to vary pro-

¹ *Du Bois Reymond's Archiv*, 1895, p. 385.

portionally to the uric acid and extractive nitrogen and not to the total nitrogen and sulphur.

CONCLUSIONS.

Our observations show the following changes to occur in the composition of urine after excessive exercise when the subject is on a fixed and constant diet.

1. *Changes independent of sweating or condition of training.*

- (a) An increase of the total nitrogen.
- (b) An increase of urea, this accounting for most of the increase of total nitrogen.
- (c) An increase of preformed ammonia.
- (d) An increase of creatinin.
- (e) An increase of sulphate, this being proportionate to the increase of nitrogen.

2. *Changes dependent on concomitant sweating.*

- (a) A diminished amount of water.
- (b) A diminution of chloride.
- (c) A diminution of sodium.

3. *Changes observable when the subject is in poor condition but not when he is in good training.*

- (a) An increase of uric acid.
- (b) An increase of nitrogenous extractives.
- (c) An increase of phosphoric acid.

These changes in the composition of the urine indicate the following metabolic changes:

(1) That excessive muscular work causes an increased catabolism of protein, this being shown by the increased excretions of nitrogen and of sulphur in the urine.

(2) That the protein consumed is muscle protein, shown by the increased nitrogen and sulphur excretions not being accompanied by increased excretions of uric acid, extractive nitrogen and phosphorus, muscle being a tissue poor in nucleo proteins which produce these waste products.

(3) That, if the subject who performs excessive muscular work be in poor training, this consumption of muscle protein is accompanied by the consumption of the protein of other tissues which contain nucleo proteins, as shown by the increased excretions of uric acid,

extractive nitrogen and phosphorus. There may here be a withdrawal of proteids from other structures to effect repair in muscles, similar to the transference of material seen in starvation, the proteid portion being retained, while the nucleic acid portion is excreted.

Our observations on the effect of sweating do not indicate any marked influence on the metabolism. The changes in the urine following profuse sweating are a diminution of water, a diminution of hydrochloric acid and of sodium, and a slight diminution of nitrogen, these changes being easily explained by the loss of those substances in the sweat, do not in any way indicate a diminished production or secretion. The concomitant occurrence of sweating along with excessive muscular exercise can only affect the observation of changes produced, by masking changes in the amount of water, hydrochloric acid and sodium excreted in the urine, and slightly diminishing the increased excretion of nitrogen.

Our observation on the influence of massage on metabolism also gives negative results. The changes observed, an increased excretion of water and a slightly increased excretion of phosphorus, being readily attributed to the physical influence of the increased lymph flow drawing these from the tissues, and not indicating any increased katabolism. The changes produced by massage being so small it is fair to conclude that the changes observed to result from excessive muscular exercise are not due to the physical effects of an increased lymph flow.

Our conclusions show the importance of two points long known to athletes and others doing excessive muscular work. The one is the importance of proper training, for by it an abstraction of proteid matter from tissues other than muscle can be avoided, the other is the importance of there being a sufficiency of proteid in the diet to compensate for the loss which occurs. An abundance of proteid in the diet of an athlete has other functions to fulfil besides this, it is required during training for building up the energy liberating mechanism—the protoplasm of muscle¹, and it is also required after work to repair that mechanism. The benefits of training are well known in other ways, such as preparing the heart for suddenly increased duty and limiting the after fatigue effects, but the effect of training touched upon in this paper, in modifying the influence of excessive muscular work on the metabolism, and showing in a tangible way its benefit, is of considerable importance.

¹ *Edinburgh Medical Journal*, June 1895.



